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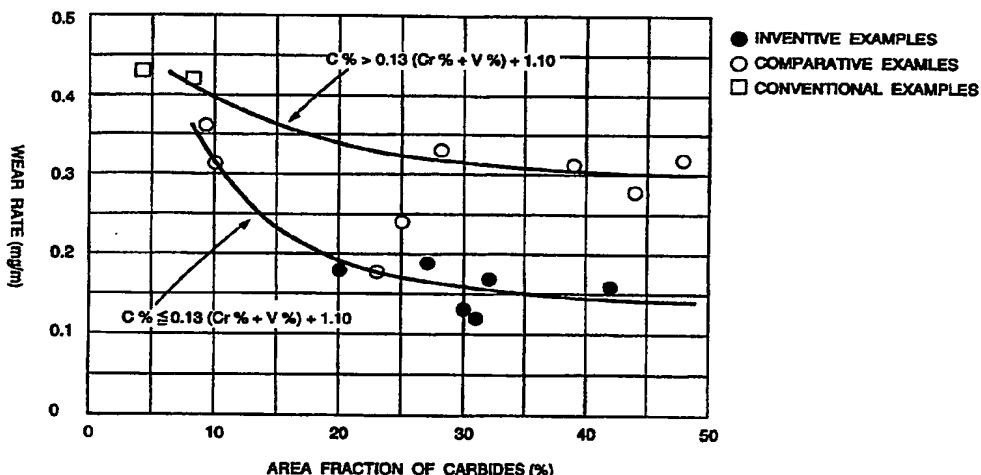
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(54) Rolling bearing

(57) In a rolling bearing in which at least one of an inner race, outer race and rolling elements is made of an alloy steel containing 0.2 to 1.0 wt% of carbon, 3.0 to 14.0 wt% of chromium, 0.8 to 3.0 wt% of vanadium, and up to 3.0 wt% molybdenum, the balance being iron, the part being carburized or carbonitrided, followed by hardening and tempering to secure that the surface carbon concentration C% and the concentrations Cr% + V% of chromium and vanadium, respectively, satisfy a relationship of C% ≤ 0.13 (Cr% + V%) + 1.10 and that carbides have an area coverage of 15 to 50%. The rolling bearing has an extended service life even if it is used under lubrication in the presence of foreign matter and exhibits superior wear resistance to be hard to wear even if an oil film breakage occurs.

FIG. 3



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FIG. 1

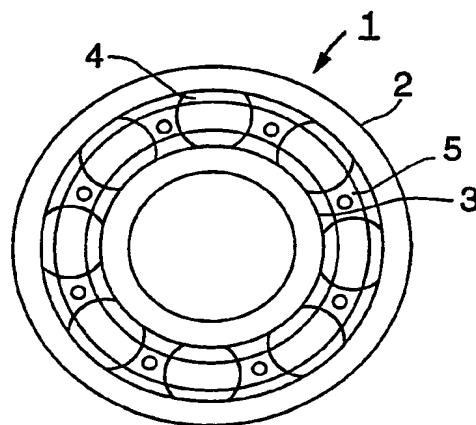


FIG. 2A

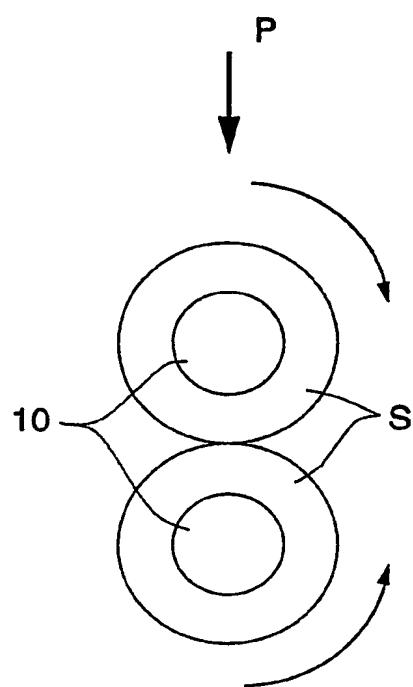


FIG. 2B

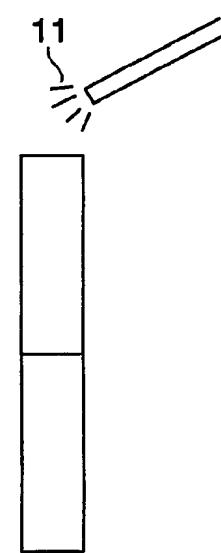


FIG. 3

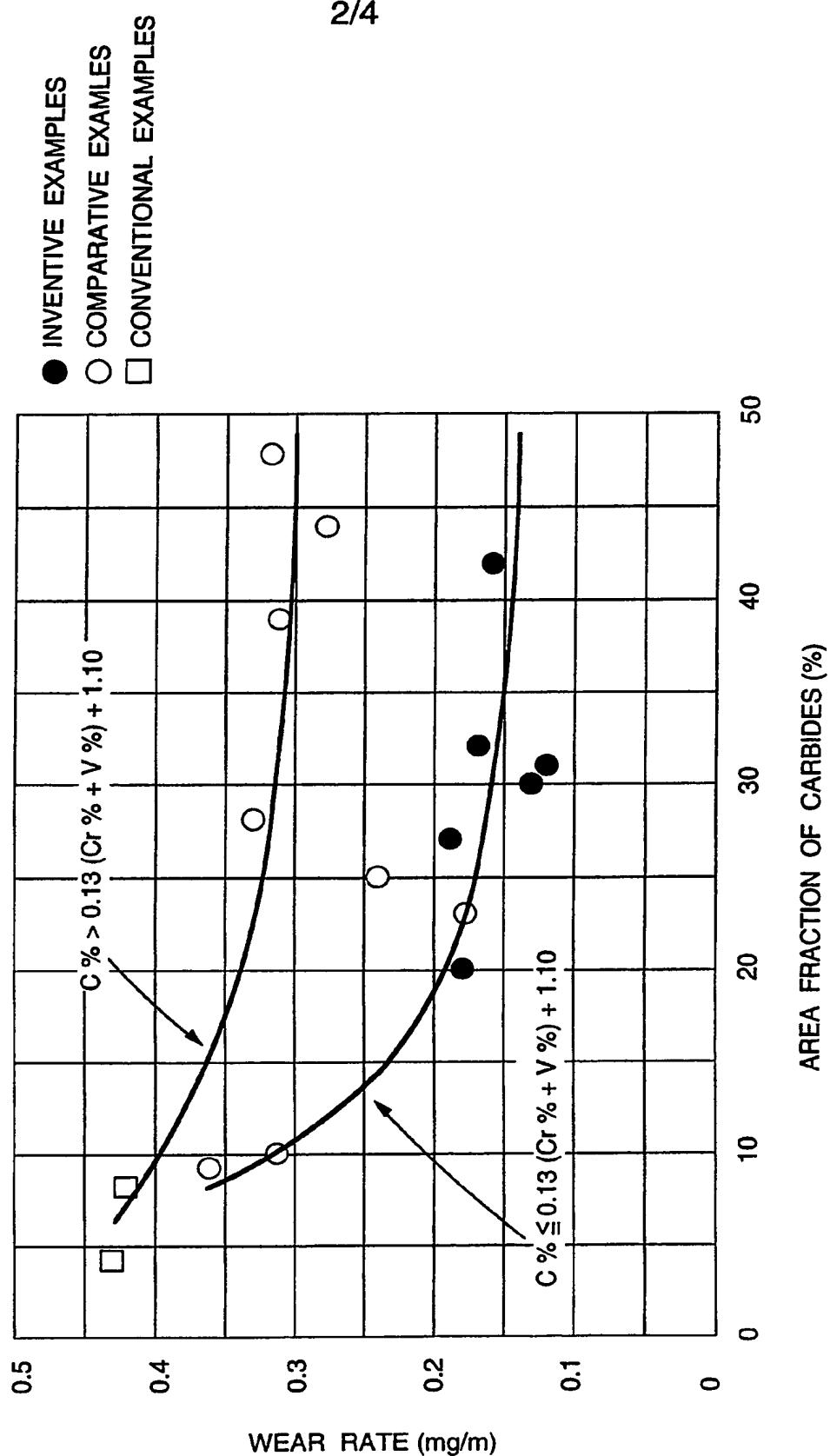


FIG. 4

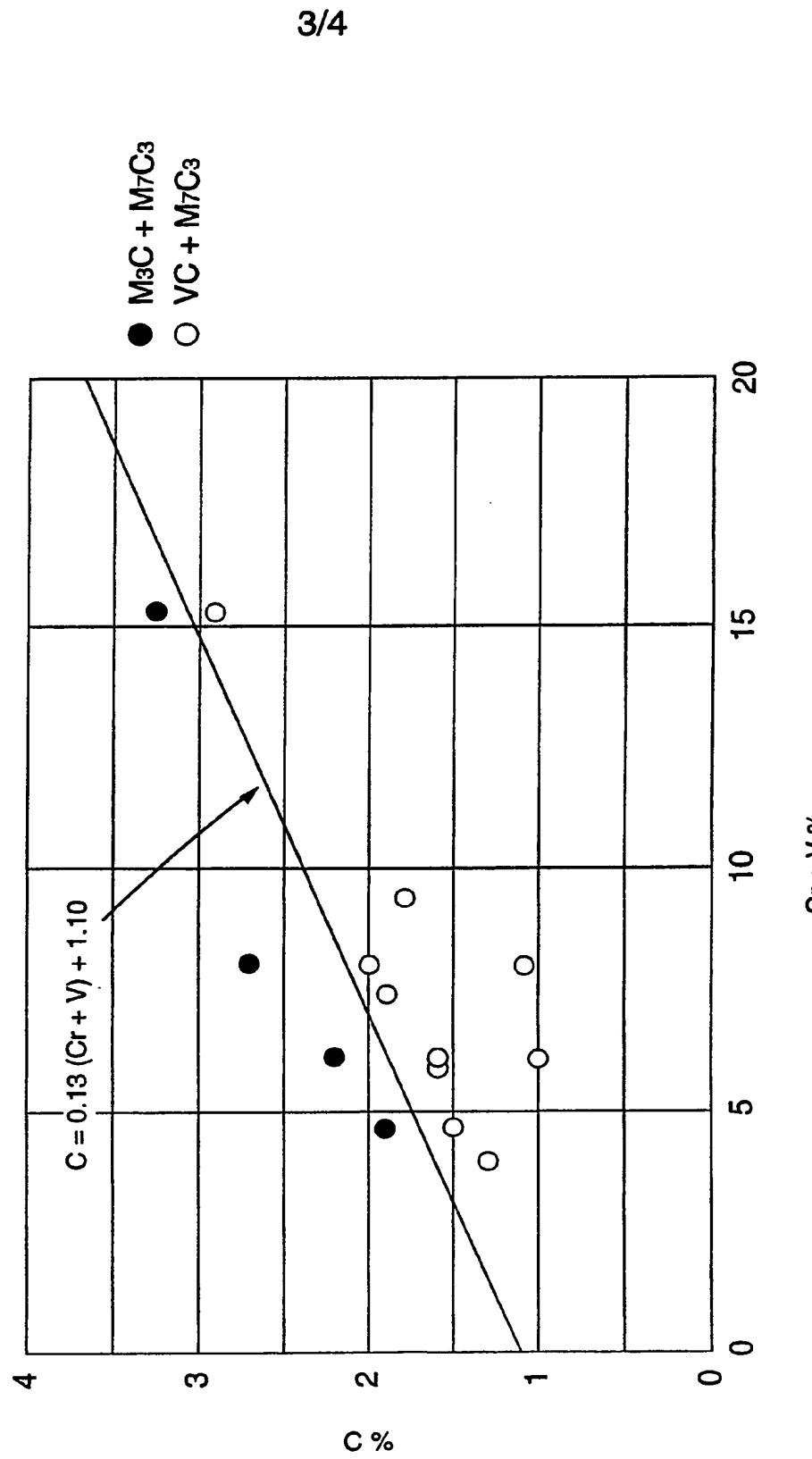
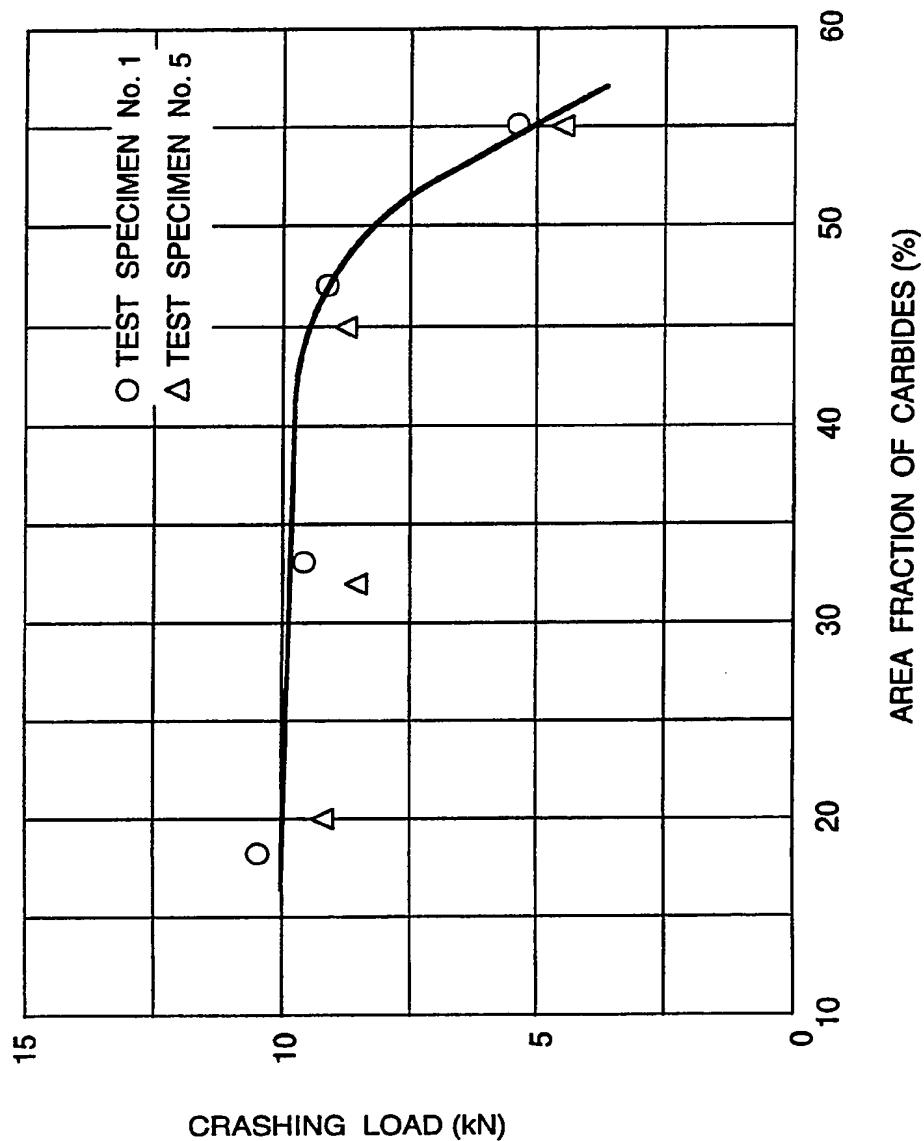


FIG. 5

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ROLLING BEARING

5 The present invention relates to a rolling bearing for use in vehicles, agricultural machines, construction machines, steel making machines or the like. More specifically, the present invention relates to a rolling bearing for use in which long service life and high wear resistance are required.

10 Rolling bearings are used under extremely severe conditions such that they are subjected to repeated shearing stress under high areal pressure. In order to withstand the applied shearing stress to thereby secure the necessary rolling fatigue life, conventional rolling bearings have been made of 15 a high-carbon chromium bearing steel (SUJ 2), which is hardened and tempered to provide the hardness of H_RC 58 to 64.

20 Case hardening steels (e.g. SCR 420, SCM 420, SAE 4320H, and the like) have also been used in rolling bearings. To secure the required service life, those steels are carburized or carbonitrided, followed by hardening and tempering so as to have the surface hardness of H_RC 58 to 64 and the core hardness of H_RC 30 to 48.

25 Recently, since it tends to require vehicles with higher speed performance, lighter weight and better fuel economy, as well as steel making facilities with minimum

maintenance, the conditions for the use of bearings become extremely severe. Under the circumstances, there have been caused several problems such as the flaking of the bearing surface due to the damage caused by foreign matter, 5 contamination and debris entering the lubricant, progressive wear due to insufficient lubrication and the like. On the other hand, there is an increasing demand for extending the service life of bearings under the severe conditions.

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To deal with this situation, for example, Unexamined Japanese Patent Publication No. Hei. 2-277764 have proposed a method in which a high chromium steel is carburized or carbonitrided to precipitate fine grained carbides in a 15 bearing surface layer and the amount of residual austenite is limited in an appropriate range so as to assure a longer life under lubrication in the presence of foreign matter. This method, however, has not given entire consideration to the wear due to the insufficient lubrication.

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According to the present invention a rolling bearing comprises an inner race, an outer race and a plurality of rolling elements, in which at least one member of the inner race, the outer race and the rolling elements is 25 made of an alloy steel containing:

0.2 to 1.0 wt% of carbon;
3.0 to 14.0 wt% of chromium;
0.8 to 3.0 wt% of vanadium;

up to 3.0 wt% of molybdenum; and
the balance being iron,
the member being carburized or carbonitrided, followed by
hardening and tempering to satisfy a relationship of
5 $C\% \leq 0.13 (Cr\% + V\%) + 1.10$
and to satisfy that carbides present on a surface have an
area fraction of 15 to 50%, where C% is a surface carbon
concentration and Cr% and V% are the surface concentrations
of chromium and vanadium, respectively.

10

An example of the present invention will now be
described in detail with reference to the accompanying
drawings, in which:-

15 Fig. 1 is a front view of an embodiment of the rolling
bearing of the present invention;

Fig. 2A is a front view for illustrating a two
cylinder wear tester, and Fig. 2B is a side view thereof;

20 Fig. 3 is a graph showing the relationship between
wear rates and carbide's area coverage, compared with test
specimens of inventive, comparative and conventional
examples;

25 Fig. 4 is a graph showing the relationship between the
concentration of carbon and the combined concentrations of
chromium and vanadium relative to the carbide structure in
the test specimens; and

Fig. 5 is a graph showing the relationship between the carbide's area coverage and crushing loads in crushing tests.

5 One method known to be effective in improving the wear
resistance of bearing materials is the addition of large
amounts of carbide forming elements such as Cr, Mo and V so
that carbides are present in the bearing's surface layer
precipitated in large quantities in the bearing's surface
10 layer. This method is based on the idea of providing
better wear resistance by increasing the amount of carbides
to such an extent that the service life is not adversely
affected. On the other hand, the present inventors aim at
the carbide structure and the amount of carbides present in
15 the bearing's surface layer and studied the relationship
between the carbide structure and the amount of carbides
present in the bearing's surface layer, the service life
and the wear resistance of bearings. As a result, the
inventors found out that the addition of V to have

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VC-type carbides precipitated was extremely effective in improving the wear resistance of bearings.

Further, the inventors found out that when the concentrations of Cr and V satisfied a specified relationship with the concentration of C, extremely fine-grained and hard VC-type carbides were precipitated while preventing coarse and brittle M_2C -type carbides from precipitating. In addition, by limiting the area fraction of carbides to be within a specified range, a rolling bearing could be produced that had not only superior wear resistance but also an extending service life. The present invention has been accomplished on the basis of these findings.

There are described in below the functions of the elements contained in the rolling bearing of the present invention, as well as the criticality of the content of each element.

C: 0.2 to 1.0 wt%

Carbon is the essential element for forming carbides and transforming the base metal to martensite so as to increase the hardness after hardening and tempering.

The carbon content is set to at least 0.2 wt% in order to prevent reticulate coarse carbides from precipitating at grain boundaries as a mixed structure of an austenitic phase and unsolved carbides during carburizing or carbonitriding. The upper limit of the carbon content is set to 1.0 wt% because the toughness of the core of the bearing is deteriorated if

carbon is contained in amounts greater than 1.0 wt%.

Cr: 3.0 to 14.0 wt%

5 Chromium improves hardenability and functions to the solid solution strengthening of the base metal. Additionally, if Cr is added in a large amount, the carbides produced by carburizing or carbonitriding are transformed to M_3C , type having such a property as to make the carbides hard and slow in grain growth to prevent from becoming coarse, so that the addition of Cr contributes to the improvement of the rolling 10 fatigue strength.

15 The lower limit of the chromium content is set to 3.0 wt% in order to strengthen the base metal while securing to prevent from producing coarse M_3C -type carbides. The upper limit of the chromium content is set to 14.0 wt% because if the upper limit is exceeded, macro carbides are produced in a stage of raw materials and stress concentration occurs around the carbides to deteriorate the service life.

V: 0.8 to 3.0 wt%

20 Vanadium is an element which is effective to increase the resisting property for temper softening and to produce extremely fine-grained and hard VC carbides, so that the addition of V contributes to the improvement of wear resistance and life property.

25 The lower limit of the vanadium content is set to 0.8 wt% because the addition effect of vanadium is not sufficiently exhibited if it is added in less than 0.8 wt%. The upper limit

of the vanadium content is set to 3.0 wt% because excess addition of vanadium not only deteriorates grindability but also becomes higher in cost.

Mo: ≤ 3.0 wt%

5 Molybdenum is a selective element which is effective to increase the resisting property for temper softening, similarly to vanadium. The addition of Mo, which is similar to chromium, also serves to improve the rolling fatigue strength by preventing the coarse-graining of carbides which are 10 precipitated as the result of carburizing or carbonitriding.

The upper limit of the Mo content is set to 3.0 wt% because excess addition of Mo not only deteriorates the plastic workability but also becomes higher in cost.

C% ≤ 0.13 (Cr% + V%) + 1.10

15 As described in detail below, the surface carbon concentration attained by carburizing or carbonitriding must satisfy the following relationship with the concentrations of Cr and V:

$$C\% \leq 0.13 (Cr\% + V\%) + 1.10$$

20 and that the area coverage of the carbides is set to a range of 15 to 50%.

25 If the surface carbon concentration satisfies the relation of $C\% \leq 0.13(Cr\% + V\%) + 1.10$, extremely fine-grained and hard VC-type carbides are precipitated, so that the precipitation strengthening achieves a remarkable improvement in wear resistance. In contrast, if the surface carbon

concentration indicates the relation of $C\% > 0.13(Cr\%+V\%)+1.10$, the coarse and brittle M_3C -type carbides are precipitated, so that the improvement in wear resistance becomes insufficient.

5 If the area coverage of the carbides exceeds 15%, the improvement in wear resistance is remarkable. However, if the area coverage of the carbides exceeds 50%, the raw materials containing the carbides are extremely deteriorated in mechanical strength.

Examples

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Fig. 1 is a front view of an embodiment of the rolling bearing 1 of the present invention. The rolling bearing 1 includes an outer race 2, an inner race 3, rolling elements 4 and a cage 5.

15 Various alloy compositions of raw materials used for the rolling bearing 1 are indicated in Table 1.

Table 1

<u>No.</u>	<u>C</u>	<u>Cr</u>	<u>V</u>	<u>Mo</u>	<u>Remarks</u>	
5	1	0.3	3.2	1.4	-	Invention
	2	0.4	7.8	1.5	-	Invention
	3	0.4	13.8	1.5	-	Invention
	4	0.7	5.1	0.9	-	Invention
	5	0.8	5.3	2.6	-	Invention
	6	0.8	5.0	2.3	2.4	Invention
10	7	0.5	5.3	0.5	-	Comparison
	8	0.5	1.8	2.1	-	Comparison
	9	1.0	1.5	-	-	Convention
	10	0.2	1.0	-	-	Convention

Alloy composition Nos. 1 to 6 are alloy steels in accordance with the present invention. Alloy composition No. 7 is an alloy steel outside the scope of the present invention in terms of the vanadium content. Alloy composition No. 8 is an alloy steel outside the scope of the present invention in terms of the chromium content. Alloy composition No. 9 (JIS SUJ 2) and No. 10 (JIS SCR 420) are alloy steels free of vanadium and also outside the scope of the present invention in terms of chromium content.

Comparative tests for confirming the effect of the present invention were conducted as shown in Table 2. Test Specimens A to P were

formed of the respective alloy steels having the compositions shown in Table 1. The thus prepared inner races were subjected to heat treatments such as carburizing, hardening and the like. The heat treatments were

performed under the following conditions.

Test Specimens A to F according to the present invention and Test Specimens G to N serving as comparative examples were subjected to the carburizing which was performed in a carburizing gas atmosphere at 920 to 950°C for 4 to 8 hours, followed by hardening and subsequently tempering at 180°C for 2 hours. Further, in the case where the carbonitriding was performed, a carbonitriding temperature was set to 840 to 870°C and ammonia gas 3 to 5% was added in the carburizing gas atmosphere. The other carbonitriding conditions were similar to the carburizing and hardening treatment.

Test Specimen O formed of steel species SUJ 2 was subjected to the hardening at 840°C, followed by tempering at 180°C for 2 hours.

Test Specimen P formed of steel species SCR 420 was subjected to the carburizing at 930°C for 4 hours, followed by secondary hardening at 860°C and tempering at 180°C for 2 hours.

The test specimens subjected by the necessary heat treatments were evaluated for heat treatments quality (in terms of the surface carbon concentration and the area coverage of carbides). In addition, they were subjected to wear tests and life tests. The results were then compared.

The term "surface carbon concentration" as used herein means the average carbon concentration (wt%) in a range from a

diameter surface of an inner race serving as the test specimens to a depth which is equivalent to 2% of the outer diameter of the inner race. The term "the area fraction of carbides" indicates the proportion measured in the surface.

5 The wear tests were conducted with a two-cylinder wear tester as shown in Figs. 2A and 2B. Test specimens S were mounted on a pair of cylinders 10 vertically opposing to each other, which were held in mutual contact and rotated contrary at low speed under a load P that applies from above of the wear tester. The wear rates (mg/m) relative to both specimens S were measured to obtain the average value. In order to test for wear resistance under insufficient lubrication, the rotating specimens were supplied with a lubricant 11 which was so low in viscosity that an oil film was easy to break.

10

15 The specific conditions for the wear test were as follows.

Load	100 kgf
Areal pressure	100 kgf/mm ²
Rotational speed	10 rpm
20 Slip ratio	30%
Lubricant	# 10 spindle oil
Oil temperature	60°C

25 The life test was conducted with a thrust rolling life tester under lubrication in the presence of foreign matter. The thrust rolling life tester is disclosed in "Guide for special steel (1st edition)", edited by the Institute of Electric Steel, RIKO-GAKUSHA, 1965, Ch.10, p 21.

The specific conditions for the life test were as follows:

Load	655 kgf
Areal pressure	500 kgf/mm ²
Rotational speed	1,000 rpm
Lubricant	#68 turbine oil
Foreign matter	Steel powder (SUS 420 J2); hardness H _R C 52; particle size, 80 to 160 μ m
Concentration of foreign matter	300 ppm

The results of the wear and life test are shown in Table 2.

The wear rates (mg/m) shown in Table 2 were obtained by using the two cylinder wear tester with two cylinder test specimens having dimensions of 30 mm in outer diameter, 16 mm in inner diameter, and 7 mm in width, in addition, the balls (outer diameter of 3/8 inch) which were used in the above described thrust rolling life test as the rolling elements. The wear rates (mg/m) were obtained in the surface carbon concentration (wt%) providing the two cylinder test specimens with the average carbon concentration in a range from a surface to a depth which was equivalent to 2% of the outer diameter of the ball.

Table 2

<u>Test Specimen</u>	<u>Alloy</u>	<u>Surface carbon concentration (wt⁸)</u>	<u>Area coverage of carbides (%)</u>	<u>Heat treatment</u>	<u>Wear rate (mg/m)</u>	<u>L_{10} life (x 10⁶ cycles)</u>	<u>Remarks</u>
A	1	1.5	20	carburizing and hardening	0.18	17.8	Invention
B	2	1.8	32	do.	0.17	20.2	Invention
C	3	2.9	42	do.	0.16	21.1	Invention
D	4	1.6	27	do.	0.19	16.4	Invention
-	E	5	2.0	31	do.	0.12	Invention
-	F	6	1.9	30	do.	0.13	Invention
-	G	1	1.9	28	do.	0.33	Comparison
-	H	3	3.3	48	do.	0.32	Comparison
-	I	4	2.2	39	do.	0.31	Comparison
-	J	5	2.7	44	do.	0.28	Comparison
-	K	4	0.9	9	do.	0.36	Comparison
-	L	5	1.0	10	do.	0.31	Comparison
-	M	7	1.6	25	do.	0.24	Comparison
-	N	8	1.3	23	do.	0.18	Comparison
-	O	9	1.0	8	through hardening	0.42	Convention
-	P	10	0.9	4	carburizing and hardening	0.43	Convention

As is apparent from Table 2, Test Specimens A to E according to the present invention were at least twice the wear resistance and service life of Test Specimens O and P as conventional examples. Test Specimen F, which 5 additionally had 2.4 wt% Mo, were more long-lived than Test Specimens A to E.

Test Specimens G to J were comparative examples having excessively high concentrations of C. Since they had coarse and brittle M_2C -type carbides precipitated on the 10 surface, the improvement in wear resistance was not sufficient. Test Specimens K and L were comparative examples having excessively small carbide contents. Also, the improvement in wear resistance was not sufficient.

Test Specimen M had vanadium V added in an amount 15 less than the lower limit specified by the present invention. Evidently, the improvement in wear resistance was not sufficient. Test Specimen N had chromium Cr added in an amount less than the lower limit specified by the present invention. Evidently, the improvement of life 20 property was not sufficient.

Fig. 3 shows the relationship between the area coverage of carbides and the wear rate. When the area coverage of carbides exceeded 15%, the improvement in wear 25 resistance was remarkable. As is also apparent from Fig. 3, the wear resistance was extremely superior when the relation of $0\% \leq 0.13(Cr\% + V\%) + 1.10$ was satisfied.

Fig. 4 shows the relationship between the concentration of Cr + V and C present in the surface layer relative to the carbide

structure. The area under the straight line expressed by $C=0.13(Cr+V)+1.10$ refers to the range of examples according to the present invention. The area above the straight line refers to the range of comparative examples.

Additionally, in order to check the mechanical strength of Alloy Composition Nos. 1 and 5, ring-shaped test pieces (inner diameter 13 mm; outer diameter 20 mm; width, 8 mm) were made of those compositions and subjected to crushing tests. The thus prepared test pieces were carburized at 920 to 950°C for 4 to 8 hours, followed by hardening and tempering at 180°C for 2 hours, and grinding to the specified dimensions. The test pieces had varying area coverages of carbides on the surface to conduct the crushing tests.

The crushing tests were conducted at a ram speed of 0.5 mm/min, using an autograph made by Shimadzu Corp. The test result is shown in Fig. 5. Evidently, the crushing load was abruptly deteriorated when the area coverage of carbides exceeded 50%.

The above-described examples refer to the case where the present invention is applied to the inner race of a rolling bearing. The present invention is applicable, either individually or wholly, to the other components of a rolling bearing such as the outer race and rolling

elements. In the case where the present invention is applied to the rolling elements, the surface carbon concentration is defined by the average carbon concentration (w%) in a range from a surface of the rolling element to a depth which is equivalent to 2% of the diameter of the rolling element.

As for the heat treatment, the present invention is also applicable to the rolling bearing subjected by 10 carbonitriding as well as carburizing.

In the present invention, extremely fine grained and hard VC type carbides are precipitated in the steel structure while coarse and brittle M_3C -type carbides are 15 prevented from precipitating; thus, the rolling load concentrating at the edges of indentations which form on the respective surfaces of the inner and outer races and the rolling elements in a rolling bearing as the result of repeated contact with the foreign matter in a lubricant is 20 effectively mitigated to prevent the occurrence of micro-cracks and achieve a remarkable improvement in the wear resistance of the bearing. Hence, the rolling bearing of the present invention is long lived even if it is used under lubrication in the presence of foreign matter and, 25 additionally, it features superior wear resistance.

C L A I M S

1. A rolling bearing comprising an inner race, an outer race and a plurality of rolling elements, in which at 5 least one member of the inner race, the outer race and the rolling elements is made of an alloy steel comprising:

0.2 to 1.0 wt% of carbon;
3.0 to 14.0 wt% of chromium;
0.8 to 3.0 wt% of vanadium;
10 up to 3.0 wt% of molybdenum; and
the balance being iron,

the member being carburized or carbonitrided, followed by hardening and tempering to satisfy a relationship of:

$$C\% \leq 0.13 (Cr\% + V\%) + 1.10$$

15 and to satisfy that carbides have an area coverage 15 to 50%, where C% is a surface carbon concentration and Cr% + V% are the surface concentrations of chromium and vanadium, respectively.

20 2. A rolling bearing in which at least one of an inner race, an outer race and rolling elements is made of an alloy steel substantially as described herein in any one of the examples.

Patents Act 1977
Examiner's report to the Comptroller under Section 17
(The Search report)

Application number
GB 9514778.1

Relevant Technical Fields	Search Examiner R B LUCK
(i) UK Cl (Ed.N) C7A	Date of completion of Search 10 OCTOBER 1995
(ii) Int Cl (Ed.)	Documents considered relevant following a search in respect of Claims :- 1, 2

Categories of documents

X:	Document indicating lack of novelty or of inventive step.	P:	Document published on or after the declared priority date but before the filing date of the present application.
Y:	Document indicating lack of inventive step if combined with one or more other documents of the same category.	E:	Patent document published on or after, but with priority date earlier than, the filing date of the present application.
A:	Document indicating technological background and/or state of the art.	&:	Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages	Relevant to claim(s)
X	GB 2235212 (NIPPON SEIKO KK)	1 & 2

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